Effective Usage Of Redundancy And Flexibility In Resilient Supply Chains

EFFECTIVE USAGE OF REDUNDANCY AND FLEXIBILITY IN RESILIENT SUPPLY CHAINS

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Purpose of this paper:
Since 2001 the study of supply chain resilience has a growing attention of academics and practitioners. It addresses the recovery of systems after unexpected changes (Kamalahmadi and Parast, 2016; Linnenluecke, 2015).
Flexibility and redundancy are two prominent principles used in the literature on the resilience of a system (Rice & Caniato 2003; Linnenluecke 2015). Redundancy contributes to the system's resistance and response to disruptions (Chopra and Sodhi, 2004), and flexibility helps system to adapt to a new situation (Christopher & Peck 2004). As each of these have cost implications, a fundamental question in supply chain resilience still widely debated is related to their importance and the conditions for which each of them should be emphasised (Kamalahmadi & Parast 2016). For example, in certain cases flexibility can improve efficient use of redundant resources (Hopp, 2008), while in others flexibility can hedge risks without having redundant resources (Stecke & Kumar 2009).
In both cases, prompt information about disruptions enhances decision making related to appropriate response (Wieland & Wallenburg 2013). This means that information sharing and supply chain visibility might play a critical role in supply chain resilience (Blackhurst et al., 2011; Ponis and Koronis, 2012;Brandon-Jones, Squire and Van Rossenberg, 2014). In this study, we propose that effective usage of redundancy and flexibility depends on timely information about disruptions and their impact on the firm and its supply chain. Thus, we aim to explore in what way redundancy and flexibility affect a firm's resilience and what is the importance of supply chain visibility and information sharing in this context.

Design / methodology / approach:
This study is based on a review of recent academic papers on supply chain and firm resilience published in supply chain management related journals, as well as key theories and approaches that can be used as an introspective framework for deeper insight into constitutive elements resilience: redundancy, flexibility and visibility.

Findings:
Our major findings address a) there is a need for a better understanding which conditions are beneficial to combine or generate trade-offs between redundancy and flexibility, and when flexibility should be combined with visibility in the supply chains and b) the influence of visibility and information sharing on resilient supply chains and companies are under-represented in studies. Our findings suggest that redundancy, flexibility and information sharing/visibility are pillars of a firm's resilience.

Value:
Our research addresses fundamental issues related to the supply chain resilience: what are the academic insights on how to effectively use redundancy and flexibility, and what role information sharing and visibility have in it. This paper intends to clarify where the future directions are and contribute to the development of a theoretical perspective on supply chain resilience.

INTRODUCTION

In the last decade supply chains increasingly face a variety of risks and disruptions: from economic crisis, political risks and natural disasters, to port closures, accidents in production or storage facilities or industrial strikes (Liu et al. 2017). Thus, companies and their supply chains have to respond appropriately to these risks and disruptions while keeping their competitive position on the global market or trying to improve it.

This is reflected in increased number of academic publications that stem from research projects conducted in multiple countries and universities. Already six journal and conference papers reported a literature reviews on supply chains resilience since the beginning of 2016, which indicates growing body of the literature on this topic.

The purpose of this paper is not to add one more literature review to this literature, but to focus on dominant principles associated with the supply chain resilience (Hohenstein et al. 2015; Ali et al. 2017): redundancy, flexibility and visibility.

Redundancy, flexibility and visibility are considered as separate drivers of supply chain resilience in multiple studies. Generally, *redundancy* is considered in the context of 'passive' protection from disruptions, while *flexibility* is considered in terms of switching to back-up plans and adaptation to the new circumstances caused by a disruption. Theory highlights underlying costs of redundancy and flexibility and points out inefficiency of the systems when these two principles are not balanced (Rice Jr. & Caniato 2003). As Annarelli and Nonino (2016) state, it is not sufficient to focus on the trade-off between the redundancy and flexibility: resilience needs to be part of a decision-making process. Decision-making processes require reliable inputs, not only about achieved performances, but also alerts about potential risks and disruptions. Supply chain *visibility* is also an important element of effective and efficient use of resources (Brandon-Jones et al. 2014), which is of the utmost importance in periods of disruptions. However, influence of information sharing and visibility to supply chain resilience is investigated only in a few studies (Kamalahmadi & Parast 2016). Moreover, as redundancy contributes to the system's resistance and response to disruptions (Chopra and Sodhi, 2004), and flexibility helps the system to adapt to a new situation (Christopher & Peck 2004), there is a question how information sharing and visibility affect effective use of redundancy and flexibility. A review of extant supply chain management literature shows that only in recent studies these elements were connected (Kamalahmadi and Parast, 2016). However, to the best to our knowledge, the relationship between redundancy, flexibility, and visibility in the context of resilient supply chains has not been considered a central part in any of these studies.

The paper is structured as follows: first, we present a literature review design, and subsequently we elaborate on the key findings. The findings are discussed by taking into account two aspects – redundancy, flexibility and visibility seen as 1) key driving principles/strategies of supply chain resilience and 2) key capabilities relevant for the process of resilience. We conclude the paper with the future research directions and reflection on limitations of our study.

LITERATURE REVIEW DESIGN

To define the literature research framework, we preliminary reviewed recent studies that examine theoretical concepts of resilience: (Kamalahmadi & Parast 2016; Tukamuhabwa et al. 2015; Hohenstein et al. 2015; Ali et al. 2017; Linnenluecke 2015). We reviewed frameworks used on these studies and gaps they identified. In all these studies, the identified common denominators that impact resilience are redundancy and flexibility, as well as visibility. Though these elements are identified as important for achieving supply chain resilience, they are mostly considered independently.

The publication period: In the literature research on supply chain resilience, Kamalahmadi and Parast (2016) did not find many studies before 2000. Based on the work of (Sheffi 2005), the 9/11 event in 2001 in the US and later catastrophic events (e.g. tsunami of 2004; hurricane Katrina in 2005) is the cornerstone for expansion of a research on the supply chain resilience (Linnenluecke 2015). Thus, we identify this as the cut-off date for our search in the following databases: Science Direct, Ebsco (Business source premier), Emerald, Wiley and Taylor and Francis.

Keywords and search: The search is conducted in two cycles: the first cycle was based on the papers that contain following keywords: “supply chain”, “flexibility”, “redundancy” and “resilience”. This search resulted in 577 results. After that, in a second cycle, we refined the search by using two additional keywords: “information sharing” and “visibility”. This narrowed down the search results to 105 studies. After refinement, by using the same PRISMA procedure as Ali et al., (2017), we obtained in the first cycle 242 results, and in the second cycle 72 results. The distribution of these results shows that 1) supply chain resilience is a popular topic in the supply chain management literature; 2) redundancy and flexibility are key concepts used the literature on supply chain resilience; 3) the consideration of information sharing and visibility in context of resilience starts erratically in the period from 2003 to 2007 and then grows steadily from 2009 (Figure 1b), when supply chain resilience started being seen as a process that requires not only response and recovery, but also preparation (Ponomarov & Holcomb 2009)

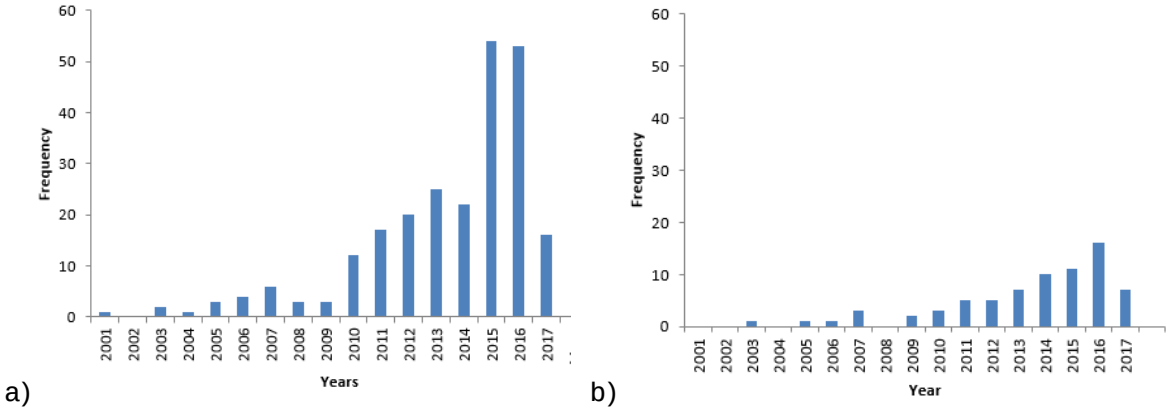

Figure 1. Distribution of publications in the period 2001-2017 (May) – a) keywords: “supply chain” resilience, flexibility, redundancy b) keywords: those used in a) and visibility and “information sharing”

Content analysis: For the purpose of this paper, we conducted content analysis on selected articles. In this analysis, we separated articles that are focused on redundancy, flexibility, visibility and information sharing as 1) key principles/strategies/drivers to achieve resilience, 2) capabilities of supply chains or companies to achieve resilience. In the group of articles focused on these key principles, we analysed the position of these elements in the used frameworks, e.g. are they primary elements that contribute to the resilience of a supply chain. In the group of articles focused on capabilities, we analysed these elements as part of proactive and reactive capabilities. Proactive capabilities mostly consider “planning for disruption” (Rice Jr. and Caniato, 2003), i.e., supply chain readiness and disruption detection, while reactive capabilities mostly consider response and recovery.

FINDINGS AND DISCUSSION

In the supply chain management literature, resilience is considered from multiple angles – the overview of definitions of resilience can be found in following studies: (Ali et al. 2017; Tukamuhabwa et al. 2015; Hohenstein et al. 2015; Linnenluecke 2015; Kamalahmadi & Parast 2016).

Kamalahmadi and Parast, (2016) found that the majority of papers are related to investigation of resilience principles, were those principles are considered as resilience capabilities, antecedents or strategies. The focus of this study is on three key principles: redundancy, flexibility and visibility, and in further text we show preliminary findings on the depth of analysis of these principles in the context of supply chain resilience. Our analysis showed that these principles are rooted in work of researchers from MIT (Y. Sheffi, J. B. Rice, Jr) and Cranfield University (M. Cristopher and H. Peck).

Thus, we use early definitions of these elements as a starting point in our study. Redundancy entails maintaining capacity in the firm to respond to disruption, while

"flexibility entails creating capabilities in the firm's organization to respond by using existing capacity that can be redirected or reallocated" (Rice Jr. & Caniato 2003, p.31). Supply chain visibility is the ability to see from one end of the chain to the other (Christopher & Peck 2004)

Resilience principles: a hierarchical order

In line with Ali et al.(2017), our review shows that flexibility and redundancy, and to the lesser extent visibility are key principles discussed and analysed in academic papers. In the papers focused on the literature reviews and surveys, these principles are often seen in hierarchical structure (Chowdhury & Quaddus 2017), that indicates which principles directly influence supply chain resilience (called first order elements), and which are part of related concepts (called higher order elements, e.g. second, third, etc.). These concepts indicate scope, i.e. what is the role of redundancy, flexibility and visibility in them, or they indicate depth, i.e., what are constitutive elements of redundancy, flexibility and visibility. Next to this hierarchical structure, there is a possible relationship between these elements in different hierarchical levels. An example of possible combinations is presented on the Figure 2.

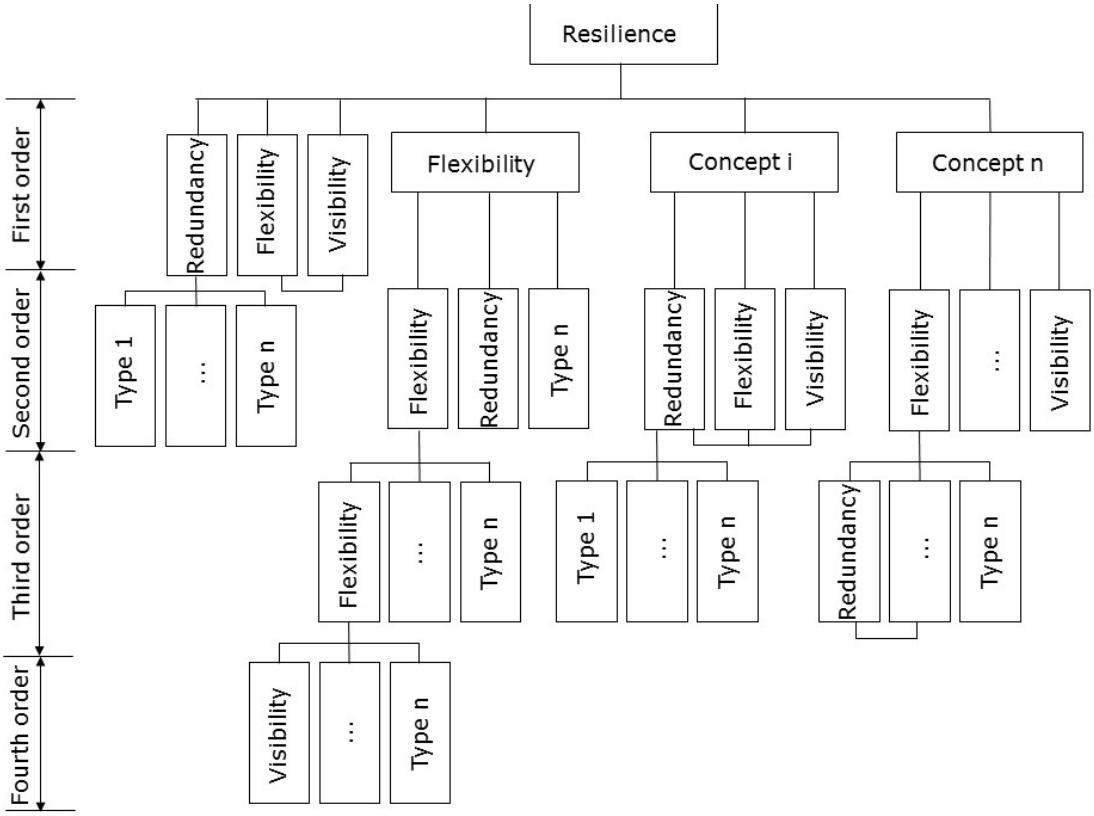

Figure 2. An example of a hierarchical position of elements considered in the analysis and possible relationships between them

Figure 2 suggest that despite of the consideration of redundancy, flexibility and visibility as key principles of supply chain resilience, there is no consensus in the literature about their relationship, as well as their placement in a hierarchical order. Ponomarov and Holcomb (2009) suggest that supply chain resilience should be seen in the context, in which case there is a need for recognition and classification of different contexts supply chain resilience appears in.

- *Redundancy, flexibility and visibility as the First Order elements*: Early studies on supply chain resilience consider redundancy and flexibility, as (one of) primary principles that directly influence supply chain resilience, while the importance of visibility is implied as a condition for rapid response to disruption (Sheffi, 2005) or

an element that can provide efficient use of flexibility (Rice and Caniato, 2003). Rice Jr. and Caniato (2003, p. 31) suggested that companies adopt a mixture of redundancy and flexibility, and that the perils of redundancy can be avoided by creating high visibility in the supply chain and increased efficiency. However, while there are studies that examine which principle provides higher resilience at lower costs (e.g. Carvalho et al., 2012), few of these studies consider the issue of visibility – in most studies it is assumed that there is an information and information sharing about the disruption which occurred somewhere in the chain.

- *Redundancy, flexibility and visibility as the Higher Order elements – in depth view*: There are studies which imply a direct connection between resilience and redundancy, flexibility or visibility, and then further develop in-depth analysis of these elements: for example, Ivanov et al. (2014) develops a model where supply chain resilience is directly related to system (structural and strategy part), process and product flexibility, and then redundancy is considered as part of structural flexibility, while visibility as recognized as important element, but not part of the model. There are also a few studies that examine connection between redundancy, flexibility and/or visibility: Brandon-Jones et al. (2014) develop a model considering that redundancy reduces the amount of information that needs to be processed, i.e. it influences supply chain visibility. Kamalahmadi and Parast (2016) suggest that information sharing and visibility represent possible first order elements, and that there is also an (obvious) connection between them which is not sufficiently studied in supply chain management literature. Similarly, Urciuoli et al. (2014) suggests that a connection between information sharing and flexibility needs more research.
- *Redundancy, flexibility and visibility as the Higher Order elements – scope view*: Considered as higher order elements, flexibility, redundancy and visibility have various positions in our hierarchical model, as well as relationships between them. For example, in early work on supply chain resilience, Christopher and Peck (2004) considered redundancy and flexibility as part of the supply chain design, and supply chain design was part of the supply chain reengineering, the second order element. In later work, Kamalahmadi and Parast (2016) considered flexibility and redundancy as second order elements, as part of supply chain reengineering that directly affects supply chain resilience. Scholten et al. (2014), on the other hand, considered redundancy, efficiency and robustness as part of the first order element of supply chain reengineering, while flexibility is considered part of supply chain agility, another first order element.

  The most consistent view of visibility together with velocity/responsiveness is as a part of supply chain agility (Scholten et al., 2014; Tukamuhabwa et al., 2015; Kamalahmadi and Parast, 2016), though in some studies flexibility takes a place in the view of agility. Other concepts that consider redundancy, flexibility and/or visibility are for example: collaboration (Scholten et al. 2014), integration (Liu et al. 2017), or frequency of information sharing (Carvalho et al. 2011). These examples suggest lack of consensus what are key elements of key concepts related to supply chain resilience and opens a door for further research.

The resilience process and its phases: capability view

In recent literature, a number of studies took resilience as dynamic capability of a supply chain (Pal et al. 2014; Chowdhury & Quaddus 2017; Brusset & Teller 2017). As the dynamic capabilities view is a branch of the Resource Based View (RBV), dynamic capabilities are considered in the context of creating a competitive advantage. As Teece, Pisano and Shuen (1997, p. 516) define, dynamic capabilities are “the firm’s ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments”, and that way achieve competitive advantage.

In multiple studies, flexibility, redundancy and visibility are seen as both, proactive and reactive capabilities (Chowdhury & Quaddus 2017) or as strategies (Ivanov et al. 2014). This view has roots in disaster studies, where pre- and post-disaster activities are considered separately (Rose 2004). Most of recent studies consider three distinctive phases of resilience: readiness, response and recovery (Chowdhury & Quaddus 2016), though

there are studies that consider these phases in more details (e.g. Sheffi and Rice Jr., 2005). Considering recent advances in information availability, as well as importance of disruption detection (Sheffi 2005), we distinguish it as a separate phase/capability of supply chain resilience (Figure 3).

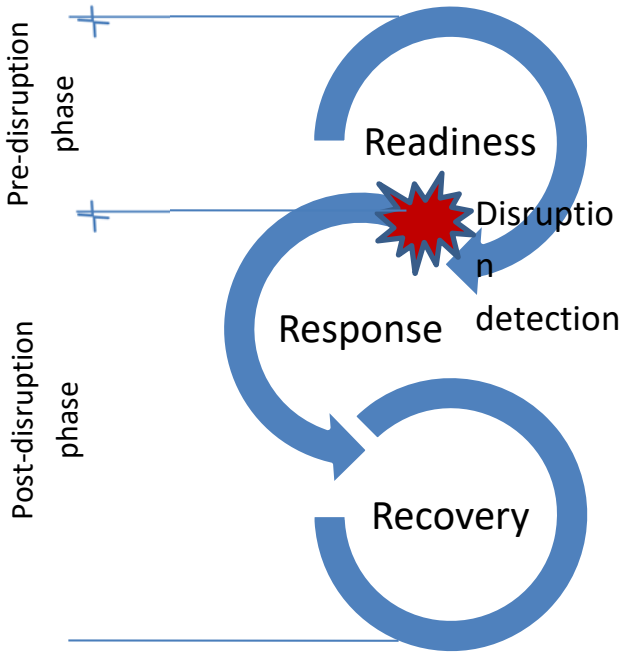

Figure 3. Phases of supply chain resilience

- In studies that consider a *proactive* view, supply chain readiness and disruption detection are important phases. Supply chain readiness is essential to overcome disruptive events and to develop resilient capability (Chowdhury and Quaddus, 2016). An emphasis is on planning and design of redundancy and flexibility into the supply chain, i.e., on preparation for a disruption (Pal et al., 2014) or disruption detection, i.e., visibility (Blackhurst et al. 2011; Brandon-Jones et al. 2014). Often the employed theory to analyse supply chain readiness is High Reliability Theory (HRT) (Weick 1987; Weick et al. 2008), which particularly focuses on high reliability organizations, avoidance of accidents and learning from them. Here, it would be interesting to explore role of redundancy, flexibility and visibility by using lens of HRT.

  As Rice and Caniato (2003) state, both redundancy and flexibility come from investments in capital and capacity, and infrastructure and capabilities, respectively, prior to the point of need. Flexibility built in contingency plans and reasonable redundancy can increase level of readiness in the supply chain (Kleindorfer & Saad 2005; Chowdhury & Quaddus 2016). Visibility is a prerequisite for response to a disruption (Wieland & Wallenburg 2013), but there are scarce studies that consider visibility while evaluating redundancy and flexibility requirements. While information sharing is necessary to enable supply chain visibility and prepare for disruption by using early warning systems , practically it can be challenging as companies might want to hide their vulnerabilities from other supply chain members (Kleindorfer & Saad 2005).
- In studies that consider a *reactive* view, the emphasis is on operationalisation of capabilities (Rice Jr. & Caniato 2003) and evaluation, i.e., how redundancy, flexibility and visibility affect response and recovery. A supply chain's ability to "quickly respond to environmental forces, reconfigure resources and to recover quickly from vulnerabilities is an essential capability", and its recovery from disruption is a unique ability of supply chains (Chowdhury & Quaddus 2016).

Chowdhury and Quaddus (2016) also mention that recovery phase is often focused on cost and time of recovery, without in depth measurement of recovery efforts.

Visibility, it is also important in the post-disruption phase, for quick coordination of recovery efforts (Brandon-Jones et al. 2014; Jüttner & Maklan 2011). Tracking and tracing (Brusset & Teller 2017), or supply chain event management (Ivanov et al. 2014) are part of early-warning systems that increase supply chain visibility. Information sharing is also one of enablers of visibility, though often overseen in connection to it. It has an important role in achieving efficient response, when connectedness between supply chain members, i.e., integration across logistics capabilities during the disruption enables supply chain resilience (Ponomarov & Holcomb 2009). Ponomarov and Holcomb (2009, p. 127) define connectedness as "systematic coordination of efforts to avoid duplication and wastefulness of services".

While redundancy and flexibility are core elements needed in each phase of supply chain resilience (Hohenstein et al. 2015), it is interesting that visibility and information sharing are under-researched; for example, disruption discovery is often take as default, and not analysed as distinctive element, (e.g. Chowdhury and Quaddus, 2017; Hohenstein et al., 2015). Rather, this is part of studies focused on resilience analysis by using operations research methods.

CONCLUSION

Based on the reviewed literature, we conclude the following key points:

- In line with Tukamuhabwa et al. (2015), who examined several principles/strategies that contribute to supply chain resilience, we found that there is a need for a better understanding which conditions are beneficial to combine or generate trade-offs between redundancy and flexibility, and when flexibility should be combined with visibility in the supply chains. Moreover, as resilience is contextual feature (Ponomarov & Holcomb 2009), there is a need to investigate whether the same recommendations would apply for SMEs and companies in the developing countries.
- Despite being recognized as important in many studies on supply chain resilience, the influence of visibility and information sharing on resilient supply chains and companies are under-represented in studies. Annarelli and Nonino (2016) suggest that research on the impact of information systems on organizational resilience is a fruitful research direction. We confirm that this branch of research has high potential, considering the growing use of the Internet in business communications, as well as the rise of internet based platforms for data storage and business applications. Moreover, there are vast opportunities for multidisciplinary teams that would cover operations research, information technology and organizational sciences/supply chain management aspects (Ivanov et al. 2014)
- A limitation of this study is in the literature review design: we considered only studies that connect flexibility, redundancy and visibility in the context of supply chain resilience. We acknowledge existence of vast amount of studies on redundancy and flexibility in more context of robustness or risks in supply chains, which could provide better information how actually redundancy and flexibility can be combined, and what is the role of visibility in it. For example, (Brandon-Jones et al. 2014) investigated redundancy and visibility as moderating variables to disruption absorption and management. Moreover, there is a need to get more insight on what kind of redundancy, flexibility or visibility modern supply chains need to increase resilience. For example, Christopher and Holweg (2011) suggests investing in structural flexibility during turbulent times, i.e. flexibility of the supply network.

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